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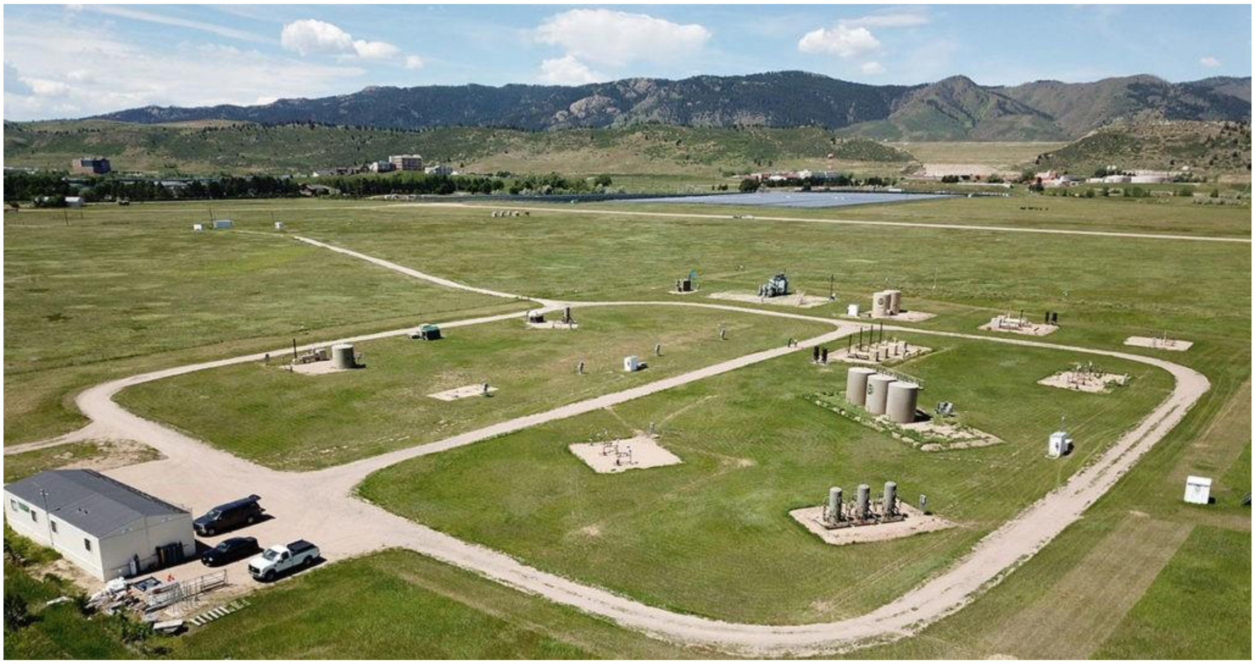

Current Project Overview

Cellular data providers, including industry giants like AT&T, Verizon, T-Mobile, and Sprint, have revolutionized the way we communicate and access information. These providers offer a wide array of plans and services that cater to various user needs. They also play a pivotal role in delivering high-speed internet access to individuals and businesses, shaping the digital landscape. This enables users to access emails, browse websites, stream videos, and engage with social media platforms while on the move. Current cellular technology has progressed through generations, each promising faster speeds, lower latency, and increased capacity. The transition from 3G to 4G LTE and now to 5G represents significant milestones in the evolution of wireless communication [1][2].

Despite the convenience and widespread availability of cellular data services, users often encounter challenges related to weak signals and dead zones [3][4]. Weak signals occur when the distance between a user's device and the nearest cell tower is substantial. Consequently, this can result in slow data speeds, disrupted calls, and difficulty accessing online content. Dead zones, on the other hand, are areas with no cellular coverage at all, often found in remote or rural regions where cell towers are scarce. Several factors contribute to these challenges [8]. Geographical obstacles, such as mountains, forests, valleys, and bodies of water, can interfere with signal propagation, creating dead zones in specific locations.

To address these challenges, cellular data providers are continually expanding their networks, adding more cell towers in underserved areas, and upgrading to advanced technologies like 4G and 5G. However, given the evolving nature of technology and the increasing demands for connectivity, ongoing research remains essential to continuously improve cellular coverage and minimize the impact of low signal areas and dead zones [5]. Addressing this issue requires significant infrastructure investments and technological advancements [6]. Cellular providers also employ signal-boosting solutions such as small cells and distributed antenna systems in urban environments to improve coverage and capacity. Despite these efforts, addressing the complexities of weak signals and dead zones remains an ongoing challenge for cellular providers.

Field measurement testing facilities such as the Methane Emissions Testing and Evaluation Center (METEC) facility use cellular data networks to transmit collected data from remote monitoring stations to central databases or analysis centers [7]. This allows for real-time or near-real-time monitoring and analysis of methane emissions. This study aims to enhance wireless connectivity at METEC, situated in northwest Fort Collins on Colorado State University's foothills campus. METEC serves as a vital research and testing site for emissions detection and quantification, methods development, and training, catering to companies seeking to evaluate the efficiency of their methane detection equipment. This project focuses on providing robust Wi-Fi and cellular data services throughout the facility, enabling seamless testing and data collection while ensuring the reliability of the equipment under evaluation.

Research Progress

The project will follow a systematic approach:

Site Survey: Perform an initial walkthrough survey of the METEC facility to establish the most effective grid layout for data collection, focusing on the edges and midpoints of seven pads in the METEC field. Identify critical testing zones and potential areas with weak or no signal. Utilize these identified points as the basis for conducting the tests.

Tests: To evaluate Wi-Fi and cellular data specifications, various tests will be conducted throughout the project. These tests include:

- **Load Test:** The objective is to assess the sustained performance of cellular routers such as Pepwave and Teltonika over an extended duration. This involves subjecting the router to typical usage scenarios, connecting it to a single device, and rigorous load scenarios by connecting it to multiple devices (including IoT devices and laptops).
- **Speed Test:** To measure the upload and download speeds of the internet connection using online speed test tools such as speedtest.com, fast.com etc. I will be measuring the speed of the cellular connection using python script and this process will be repeated for all the 3 carriers. This reflects the data transfer rate of the cellular connection.
- **Latency Test**: Checking latency and ping involves measuring the responsiveness of the network connection. This is measured by setting up a computer inside the METEC office which will be connected to Wi-Fi and acts as host. From the various defined points on the METEC pads will try to ping it. For the cellular connection I will be checking to ping google.com or some other similar servers via hard wire.
- **Signal Strength Test:** Evaluating the strength of the cellular signal from service provider. This is measured in dBm or represented as bars.

The above tests are repeated multiple times at different times of the day (early morning, noon, evening) with the permission of METEC officers for the availability to test.

Data Collection: Data will be collected via an automated code (python script) which can be executed at the points for various iterations to measure signal strength, speed, latency for Wi-Fi and various cellular providers at predetermined grid points within the facility.

Currently, I have written an automated python code which can find both uplink and downlink network speeds in Mbps. I also implemented that code in Raspberry Pi and tested the Wi-Fi speed using the script and collected raw data in csv file format.

The below figure 1 and figure 2 show the CSV file generated using the automated code which reads 30 seconds each.

```
M2023-08-25 16:36:31,11.05134462432016,5.540255678049835,40.5853,-105.0844,129.19.63.99
2023-08-25 16:37:29,0.0738770465725937,1.472513014916328,40.5853,-105.0844,129.19.63.99
2023-08-25 16:38:45,0.43185849503226065,6.888158922474576,,,129.19.63.99
2023-08-25 16:40:04,18.700419147121913,7.231782156629032,40.5853,-105.0844,129.19.63.99
2023-08-25 16:41:20,8.549886028987904,9.63843175118428,40.5853,-105.0844,129.19.63.99
2023-08-25 16:42:34,4.66541808360032,12.654521117989484,40.5853,-105.0844,129.19.63.99
2023-08-25 16:43:29,16.47492011085003,24.93190068448501,40.5853,-105.0844,129.19.63.99
2023-08-25 16:44:23,15.41670590164543,20.731780933566327,40.5853,-105.0844,129.19.63.99
2023-08-25 16:45:16,29.75871575204909,18.9817788698076,40.5853,-105.0844,129.19.63.99
2023-08-25 16:46:14,27.07781696979181,27.07602171900183,40.5853,-105.0844,129.19.63.99
2023-08-25 16:47:11,27.785352716482738,21.742932803191792,40.5853,-105.0844,129.19.63.99
2023-08-25 16:48:05,4.663370878322212,23.46760584324559,40.5853,-105.0844,129.19.63.99
2023-08-25 16:49:06,13.306553258619655,33.44575818806687,40.5853,-105.0844,129.19.63.99
2023-08-25 16:49:59,24.700907068475363,33.84250576722878,40.5853,-105.0844,129.19.63.99
2023-08-25 16:50:52,0.3018035052229871,56.86457647819069,40.5853,-105.0844,129.19.63.99
2023-08-25 16:58:07,6.579757829418501,4.079594996923544,40.5853,-105.0844,129.19.63.99
2023-08-25 16:59:13,25.367123907461043,21.424497624936492,40.5853,-105.0844,129.19.63.99
```

Fig 1. Generated CSV

```
Python 3.11.3 | packaged by Anaconda, Inc. | (main, Apr 19 2023, 23:46:34) [MSC v.1916 64 bit (AMD64)]
Data collected at 2023-08-29 18:24:51:
Download Speed: 41.65 Mbps
Upload Speed: 43.17 Mbps
Latitude: 40.5853
Longitude: -105.0844
IP Address: 129.19.63.106

Data collected at 2023-08-29 18:25:49:
Download Speed: 35.52 Mbps
Upload Speed: 40.67 Mbps
Latitude: 40.5853
Longitude: -105.0844
IP Address: 129.19.63.106
```

Fig 2. Stats of the network.

Research Plans

The next step is to repeat the above steps for all the cellular routers and data providers. After getting the data from all the points, I will proceed with the below steps:
Analysis: Analyze the collected data to assess signal strength variations, speed, latency, identify areas of weak connectivity, and ascertain the most reliable connectivity options.

Site Improvement Recommendations: Based on the analysis, provide recommendations (range of the Wi-fi, signal strength, etc.) for infrastructure and technological enhancements to address connectivity issues and would be beneficial for METEC 2.0.

Report Generation: Compile a final report summarizing the project's objectives, methodology, findings, and recommendations. Create heatmaps to visually represent signal coverage for each technology.
The project will yield the following deliverables:

- A detailed project plan outlining objectives, methodology, and schedule.
- Raw signal strength data collected on a predetermined grid for Wi-Fi and various cellular data providers (CSV file).
- A comprehensive final report presenting project results CSV file, including heatmaps showcasing signal coverage for each technology.

Publications
No Publications

Literature cited:

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4. Shaik, Altaf, et al. "New vulnerabilities in 4G and 5G cellular access network protocols: exposing device capabilities." *Proceedings of the 12th Conference on Security and Privacy in Wireless and Mobile Networks*. 2019.
5. Cabral, Alex, Vaishnavi Ranganathan, and Jim Waldo. "Cellular LTE and Solar Energy Harvesting for Long-Term, Reliable Urban Sensor Networks: Challenges and Opportunities." *arXiv preprint arXiv:2307.04016* (2023).
6. Parchin, Naser Ojaroudi, et al. "A broadband multiple-input multiple-output loop antenna array for 5G cellular communications." *AEU-International Journal of Electronics and Communications* 127 (2020): 153476.
7. Riddick, Stuart N., et al. "Measuring methane emissions from abandoned and active oil and gas wells in West Virginia." *Science of the Total Environment* 651 (2019): 1849-1856.